US Patent Application

of

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for

OPTICAL LITHOGRAPHY USING BOTH PHOTOMASK SURFACES

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from US provisional application 60/447,509 filed on 2/14/2003, hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to optical lithography.

BACKGROUND

Optical lithography is a processing technique where a pattern is optically transferred from a photomask to a target. A typical target is a layer of photoresist on top of a semiconductor wafer. In many cases, optical lithography is used to define a critical dimension on the target, and this critical dimension has decreased to below 0.5 microns as lithography technology has evolved. Since optical lithography is a widely used technique, there is a

substantial body of pertinent art. Much of this art is concerned with various methods of improving the fidelity of pattern transfer from photomask to target. For example, the use of a phase-shift photomask to improve contrast is one such development.

Given a high fidelity pattern transfer from photomask to target, a change in the desired target pattern generally requires creation of a new photomask. Although this requirement of a new photomask for each desired target pattern is often not unduly burdensome (e.g., in large scale production), it is indicative of a certain degree of inflexibility that necessarily follows from high fidelity pattern transfer from photomask to target.

For some applications of optical lithography, such as research and development, it is desirable to change the target pattern in a controllable manner without changing the photomask pattern. This flexibility is generally not provided by conventional optical lithography, as indicated above. Accordingly, it would be an advance in the art to provide such flexibility.

One example of such desired flexibility is gradient exposure of a mask pattern such that the resulting target pattern is non-uniformly exposed. A recent paper by Cao et al. (Applied Physics Letters, 81(16), pp 3058-3060, Oct 2002) demonstrates a method for gradient exposure where the photomask is non-uniformly illuminated, due to insertion of a blocking structure between the light source and photomask. Light diffraction from the edge of the blocking structure provides the non-uniform illumination of the mask.

The technique of Cao et al. has several disadvantages. Since the blocking structure and photomask are physically separated, it is difficult to align features in the blocking structure to features in the mask. Furthermore, the blocking structure of Cao et al. is inserted into the optical path between the light source and the photomask. Such insertion may be inconvenient or even impossible depending on the configuration of the lithography instrument being used.

Accordingly, there is an unmet need in the art for an optical lithography method providing improved pattern

flexibility and ease of alignment which is also compatible with commonly used optical lithography equipment.

SUMMARY

The present invention provides a method for performing optical lithography. Light is transmitted through a photomask to impinge on a target. The photomask has two mask patterns on two opposing mask surfaces separated by a transparent substrate. Light is transmitted through the first mask pattern and propagates to the second mask pattern, thereby forming a propagation pattern at that location. Light from the propagation pattern is transmitted through the second mask pattern and impinges on the target, thereby creating a target pattern. An advantage of the present invention is that the target pattern can be changed without changing either of the mask patterns. A further advantage of the present invention is that gradient exposure of a mask pattern is facilitated. The invention also provides ease of alignment of the first mask pattern to the second mask pattern, and compatibility with standard photolithography equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a shows an optical lithography method according to an embodiment of the invention.

Fig. 1b shows an intensity distribution of a propagation pattern of the embodiment of **Fig. 1a**.

Fig. 2a shows an optical lithography method according to another embodiment of the invention.

Fig. 2b shows an intensity distribution of a propagation pattern of the embodiment of **Fig. 2a**.

DETAILED DESCRIPTION

Fig. 1a shows an optical lithography method according to an embodiment of the invention. Light **102** is transmitted through a photomask **106** to impinge on a target **122**. Photomask **106** has a first surface **114** and a second surface **120** on opposite sides of a transparent substrate **116**. Transparent substrate **116** is preferably Schott Borofloat® glass, since this product has excellent surface finish and flatness, but any transparent material can be used for substrate **116**. Substrate **116** preferably has a thickness from about 0.3 mm to about 5 mm, and more preferably is about 0.7 mm thick.

A first mask pattern **104** is disposed on first surface **114**, and a second mask pattern **108** is disposed on second

surface **120**. The material of mask patterns **106** and **108** is preferably amorphous silicon having a thickness of about 150 nm, since amorphous silicon is easy to deposit uniformly, is compatible with CMOS processing, and is opaque to ultraviolet radiation. However, any opaque material, such as chromium or iron oxide, can also be used for mask patterns **106** and **108** to practice the invention. Mask pattern layer thicknesses other than 150 nm can also be used to practice the invention.

Light **102** is transmitted through first mask pattern **104**, propagates to second surface **120**, and forms a propagation pattern **118** at second surface **120**. The optical intensity distribution of propagation pattern **118** depends in part on the distance between surfaces **114** and **120**, the wavelength (or wavelengths) of light **102**, and the geometry of first mask pattern **104**. Light from propagation pattern **118** is transmitted through second mask pattern **108** to form target pattern **110**, which impinges on target **122**. Target **122** can be, for example, a film of photoresist on top of a semiconductor wafer **112**. Target pattern **110** typically includes one or more features having a critical dimension which can be less than about 0.5 microns. Since mask patterns **104** and **108** are disposed on opposite sides of

substrate **116**, relative alignment of these two patterns can easily be provided, e.g., by use of known backside alignment procedures. This ease of alignment is one of the advantages provided by the invention.

In the embodiment of **Fig. 1a**, propagation pattern **118** preferably has a smooth, monotonic intensity distribution, as indicated by shading on **Fig. 1a**. **Fig. 1b** is a schematic plot of intensity vs. position for propagation pattern **118** of **Fig. 1a**. Such an intensity distribution is useful for performing gradient exposure of second mask pattern **108**, since target pattern **110** is basically a combination of second mask pattern **108** with the monotonic intensity gradient established by propagation pattern **118**. Thus diffraction fringes in propagation pattern **118** are undesirable in this embodiment.

For this reason, light **102** is preferably non-monochromatic light, since such light tends not to form diffraction fringes (or patterns). Non-monochromatic light **102** can include light having at least two discrete optical wavelengths, or can include light having substantially a continuous range of wavelengths. In either case, diffraction fringes in propagation pattern **118** are

effectively removed by the presence of light at multiple wavelengths.

Fig. 2a shows an optical lithography method according to another embodiment of the invention. Light **202** is transmitted through a photomask **206** to impinge on a target **222**. Mask **206** has a first surface **214** and a second surface **220** on opposite sides of a transparent substrate **216**. Transparent substrate **216** is preferably Schott Borofloat® glass, since this product has excellent surface finish and flatness, but any transparent material can be used for substrate **216**. Substrate **216** preferably has a thickness from about 0.5 mm to about 5 mm, and more preferably is about 0.7 mm thick.

A first mask pattern **204** is disposed on first surface **214**, and a second mask pattern **208** is disposed on second surface **220**. The material of mask patterns **206** and **208** is preferably amorphous silicon having a thickness of about 150 nm, but any opaque material, such as chromium or iron oxide, can also be used for mask patterns **206** and **208** to practice the invention. Mask pattern layer thicknesses other than 150 nm can also be used to practice the invention.

Light **202** is transmitted through first mask pattern **204**, propagates to second surface **220**, and forms a propagation pattern **218** at second surface **220**. The optical intensity distribution of propagation pattern **218** depends in part on the distance between surfaces **214** and **220**, the wavelength (or wavelengths) of light **202**, and the geometry of first mask pattern **204**. Light from propagation pattern **218** is transmitted through second mask pattern **208** to form target pattern **210**, which impinges on target **222**. Target **222** can be, for example, a film of photoresist on top of a semiconductor wafer **212**. Target pattern **210** typically includes one or more features having a critical dimension which can be less than about 0.5 microns. Since mask patterns **204** and **208** are disposed on opposite sides of substrate **216**, relative alignment of these two patterns can easily be provided, e.g., by use of known backside alignment procedures. This ease of alignment is one of the advantages provided by the invention.

In the embodiment of **Fig. 2a**, propagation pattern **218** has a periodic intensity distribution, as indicated by shading on **Fig. 2a**. **Fig. 2b** is a schematic plot of intensity vs. position for propagation pattern **218** of **Fig.**

2a. Target pattern **210** is basically a combination of second mask pattern **208** with propagation pattern **218**, and as a result, the diffraction fringes of propagation pattern **218** are present in target pattern **210**. In the example of **Fig. 2a**, first mask pattern **204** includes two closely spaced slits, and as a result, propagation pattern **218** is a double-slit diffraction pattern. Of course, other diffraction patterns can also be used to practice the invention, such as an Airy disk pattern (diffraction by a circular aperture) and a single-edge diffraction pattern. The spacing of the diffraction fringes in propagation pattern **218** can be altered by changing the wavelength of light **202**, which allows target pattern **210** to be varied without altering either of mask patterns **204** or **208**. Such flexibility in altering target pattern **210** is one of the advantages of the invention.

Since the embodiment of **Fig. 2a** relies on diffraction to form propagation pattern **218**, light **202** is preferably substantially at a single wavelength, since diffraction effects are thereby maximized.

The embodiments of **Figs. 1a** and **2a** are exemplary, and the invention may be practiced in many other ways than the embodiments discussed above.

For example, first mask patterns, such as **104** and **204**, can be fabricated from transparent materials, such as MgF_2, CaF_2, lithium niobate, silicon nitride, quartz or other glasses. A propagation pattern such as **118** or **218** can be formed by transmission of light through a first mask pattern of a transparent material. A transparent mask pattern operates by imposing a phase shift (relative to portions of the incident light unaffected by the mask) on selected portions of the incident light. This phase shift is preferably an odd multiple of π, but can take on any value which is not an integral multiple of 2π.

Similarly, second mask patterns, such as **108** and **208**, can be fabricated from transparent materials, such as MgF_2, CaF_2, lithium niobate, silicon nitride, quartz or other glasses. A target pattern such as **110** or **210** can be formed by transmission of propagation pattern light through a second mask pattern of a transparent material, in a manner related to phase-shift lithography.

Also, the examples of **Figs. 1a** and **2a** show contact lithography, where second mask patterns such as **108** and **208** are in close proximity to the target. The invention can also be practiced with other forms of optical lithography, such as projection or stepper-based lithography.